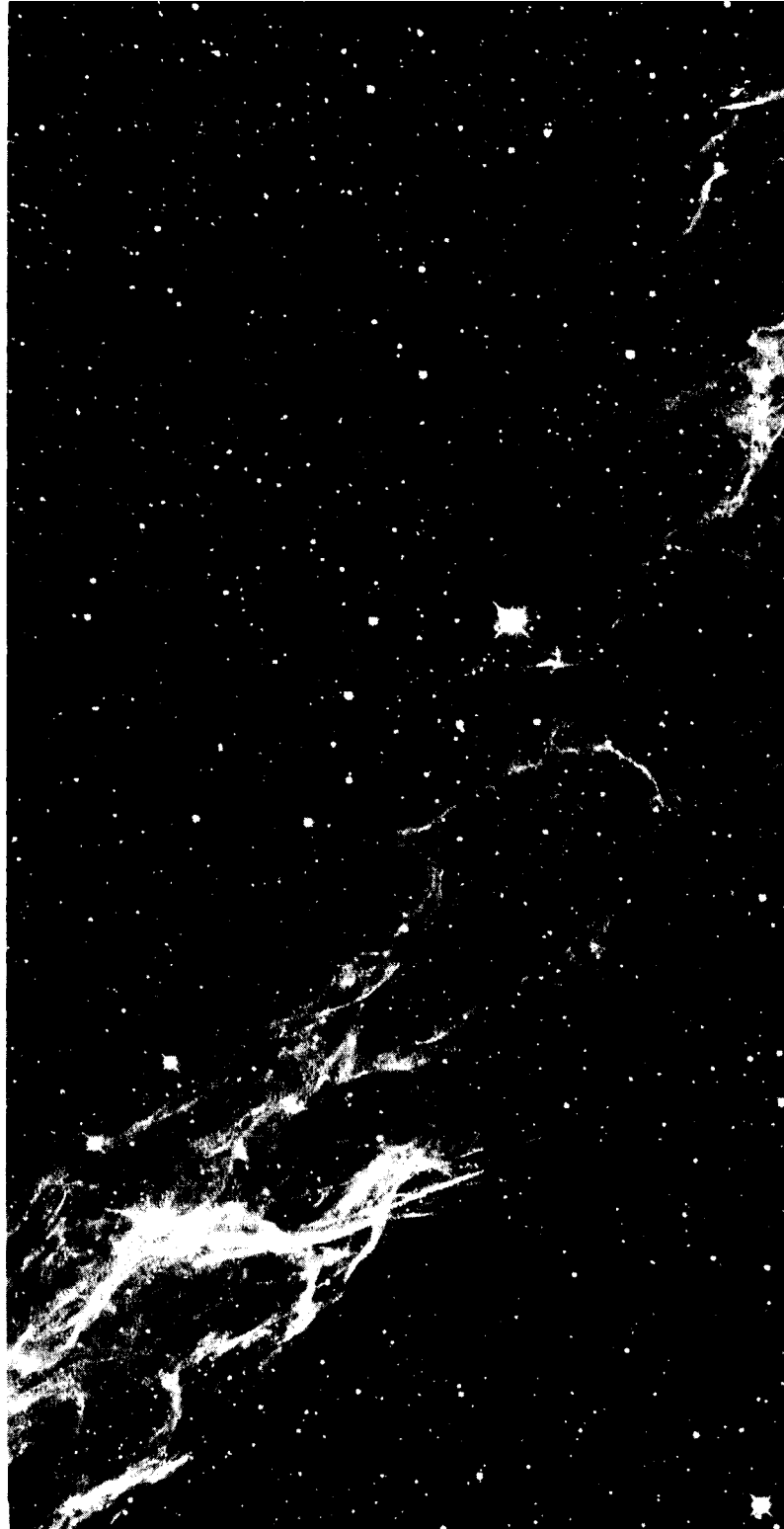




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Report No. A-4

FOURTH ANNUAL SUMMARY REPORT



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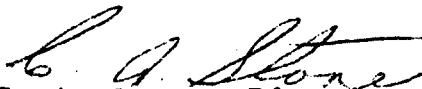
Astro Sciences Center
of
IIT Research Institute
Chicago, Illinois

for

Lunar and Planetary Programs
Office of Space Science and Applications
NASA Headquarters
Washington, D. C.

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APPROVED:


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IIT RESEARCH INSTITUTE

FOREWORD

This annual report summarizes the reports published and the special tasks performed by the Astro Sciences Center of IIT Research Institute during the 12 month period from July 1966 through June 1967. A total of twelve reports or technical memoranda are summarized together with a description of technical notes on which formal reports have not been written. In addition, 9 technical papers have been published in the open literature. The work has been performed under NASA Contract NASr-65(06).

TABLE OF CONTENTS

		<u>Page</u>
1.	INTRODUCTION	1
2.	SUMMARY OF REPORTS PUBLISHED JULY 1966-JUNE 1967	4
2.1	Reports	
	M-13 Preliminary Payload Analysis of Automated Mars Sample Return Missions	5
	M-14 Digest Report: Missions to the Outer Planets	10
	P-18 Scientific Objectives of Deep Space Investigations: The Origin and Evolution of the Solar System	12
	P-19 Scientific Objectives of Deep Space Investigations: Jupiter as an Object of Biological Interest	18
	P-20 Suggested Measurement/Instrument Requirements for Lunar Orbiter Block III	23
	P-21 Scientific Objectives for Total Planetary Exploration	26
	S-4 Thermophysical Aspects and Feasibility of Jupiter Atmospheric Entry	28
	T-18 The Accessible Regions Presentation of Gravity-Assisted Trajectories Using Jupiter	34
	T-19 On the Problem of Comet Orbit Determination for Spacecraft Intercept Missions	37

IIT RESEARCH INSTITUTE

TABLE OF CONTENTS (Cont'd)

	<u>Page</u>
2.2 Technical Memoranda	
P-15 Analytical Techniques for the Investi- gation of Distributional Features of the Asteroids	44
P-17 A Geological Analysis for Lunar Explor- ation	47
S-5 Low-Thrust and Ballistic Payload Com- parison for Jupiter Orbiter Missions	56
3. TECHNICAL NOTES	58
3.1 Prospectus 67	58
3.2 Operational Computer Codes	58
3.2.1 SPARC	59
3.2.2 Gravity Assist Accessible Regions Code	59
3.2.3 NBODY(IV)	59
3.2.4 Atmospheric Entry Calculations	59
3.2.5 Guidance and Orbit Determination	60
4. PAPERS PRESENTED AND PUBLISHED	61
4.1 The Requirements of Unmanned Space Missions to Jupiter	61
4.2 Choice of Flight Mode for Outer Planet Missions	61
4.3 Mars Surface Simulator: Design Considerations	61
4.4 Comet Orbit Determination	61

TABLE OF CONTENTS (Cont'd)

	<u>Page</u>
4.5 Missions to Mars Spur Survey of Bioclean Rooms	61
4.6 An Empirical Method for Estimating Unmanned Spacecraft Program Costs	62
4.7 Mission Requirements for the Unmanned Exploration of the Solar System	62
4.8 Post Apollo Space Exploration	62
4.9 Results of Bioclean Room Survey	62
5. BIBLIOGRAPHY OF ASC/IITRI REPORTS, TECHNICAL MEMORANDA, AND MAJOR COMPUTER CODES	63
5.1 Reports and Technical Memoranda	63
5.2 Major Computational Codes	69
5.2.1 Interplanetary Transfers	69
5.2.2 Near Planet Operations	69
5.2.3 Guidance and Orbit Determination	70
5.2.4 Combinatorial Codes	70
5.2.5 Space Sciences Codes	70
5.2.6 Special Features and Systems	71
Appendix A - REPORT DESIGNATION AND DISTRIBUTION	A-1

FOURTH ANNUAL SUMMARY REPORT

1. INTRODUCTION

The Astro Sciences Center of IIT Research Institute (ASC/IITRI) has been engaged in a continuing program of research, study, and analysis for the Lunar and Planetary Programs Division under Contract No. NASr-65(06). The contract was last renewed, for the fourth time, on November 1, 1966. This report covers the period from July 1966 through June 1967 during which a total of 140 man months of effort were expended.

The program, during the past year, has been developed and broadened to support the expanding advanced mission planning needs of NASA. At the start of this report period, a position had been reached whereby Phase 0 mission studies had been completed for early missions to the planets, asteroids, comets, and to interplanetary space. It was therefore possible this year to devote Phase 0 study effort to some more advanced and more sophisticated missions such as the Automated Mars Sample Return Mission. In addition it has been possible to start

coordinating the results of the previous studies of missions to individual targets to provide a methodology for planning the exploration of the solar system as a whole.

The areas of study necessary to meet the broad objectives of planning support can be defined briefly as:

- (a) Development, refinement, and evaluation of the scientific objectives of space exploration,
- (b) Analyses of the mission requirements for the exploration of planets, satellites, comets, and asteroids,
- (c) Analyses of the requirements for the coordinated total exploration of the solar system,
- (d) Development and maintenance of a computational capability in support of the study objectives,
- (e) Development of key elements in support of a long range plan for the exploration of the solar system.

While the ongoing activities of ASC/IITRI are reported to Lunar and Planetary Programs Division in monthly progress reports and at regularly scheduled review and planning meetings, the more tangible output is in the form of technical reports. For the 12 month period reported here a total of 21 reports and documents have been submitted. Of these, 9 will be included in Scientific and Technical Aerospace Reports (STAR) and 9 will have been published in the open literature. Summaries of these reports and technical memoranda are given in Section 2.

The technical notes of Section 3 summarize study efforts that have been performed and capabilities that exist but for which no formal reports have been written. Section 4 lists the papers published and presented as a result of work performed under this contract. Finally Section 5 is a bibliography of the reports and technical memoranda published under this contract since its inception.

2. SUMMARY OF REPORTS PUBLISHED JULY 1966-JUNE 1967

The study areas listed above have been subdivided into subject categories. All reports are identified by a code letter, indicating its technical subject category, and by a sequential number reflecting the order of submission.

The eight report categories are as follows:

- A - Annual Summary Reports
- C - Cost Estimation Methods
- M - Mission Analysis
- P - Objectives of Advanced Missions
- R - Success Probability Determinations
- S - Spacecraft Technology
- T - General Trajectory Studies
- W - Project Scheduling

An individual document in each of these categories may be published as a report, a digest report, or a technical memorandum. Reports present the results of major studies, digest reports are summaries or condensations of reports, and technical memoranda include the results of studies in narrow technical areas, interim reports and other documents involving very limited distribution. These report types are discussed together with the distribution lists in Appendix A.

2.1 Reports

Report M-13

"Preliminary Payload Analysis of Automated Mars
Sample Return Missions"

J. C. Niehoff

May 1967

Early Voyager missions to Mars may be followed by large automated biological laboratory (ABL) spacecraft designed to conduct in situ biological, geological, and meteorological analyses on the Martian surface. Recently the possibility of returning a sample of the Martian surface back to Earth for analysis has gained interest as a complement to or substitute for the ABL mission. This report is concerned with the unmanned or automated collection of a sample of the Martian surface and its return to Earth. The mission is referred to as an Automated Mars Sample Return (AMSR). The study objective was to identify by preliminary analysis AMSR mission modes which could be launched in the mid-1970's by a single Saturn V vehicle if available chemical propulsion systems were used throughout the mission. The scientific justification for returning Mars samples to Earth was not considered in this study.

The study results are presented in three parts. Firstly, the mission is subdivided into key phases and several options

are discussed for each phase. On the basis of study constraints and the restrained scope of interest (mid-1970 missions) enough relevant phase options are selected to formulate 12 candidate mission modes. Secondly, the assumptions, supporting performance analyses, and the payload determination methodology are briefly discussed. Finally, four of the 12 candidate mission modes are shown to satisfy the study constraints and be within the capability of a single Saturn V launch.

These four mission modes are summarized in the Summary Table. Modes 1-3 all use minimum energy interplanetary transfers and a long (306 day) stay time at Mars. Total trip time is 975 days. Mode 1 is distinguished by a Mars capture orbit before descent and direct return of the collected sample from the Mars' surface. Mode 2 employs a direct entry descent (no capture orbit) and direct return of the collected sample. Mode 3 uses a Mars capture orbit before descent and rendezvous in orbit before return of the collected sample to Earth. Mode 4 uses the same near-Mars options as Mode 3, but with higher energy interplanetary transfers and a Venus swingby (returning) to shorten the stay time to 12 days and the total trip time to 549 days. The required total spacecraft weight for each mode leaves a payload contingency of between 50 and 250 percent for a single Saturn V launch. However, a number of the

Summary Table

AMSR MISSION MODE SELECTION SUMMARY

	Mode 1	Mode 2	Mode 3	Mode 4
<u>Trajectory Description</u>				
Total flight time	975 days	975 days	975 days	549 days
Outbound flight time	364 days	364 days	364 days	200 days
Arrival and descent	via orbit	direct	via orbit	via orbit
Mars stay time	306 days	306 days	306 days	12 days
Launch & departure	via parking orbit	via parking orbit	via rendezvous in Mars orbit	via rendezvous in Mars orbit
Return	direct	direct	direct	Venus swingby
Return flight time	305 days	305 days	305 days	337 days
Earth reentry speed	37,650 ft/sec	37,650 ft/sec	37,650 ft/sec	39,500 ft/sec
<u>Weight Summary</u>				
Saturn V capability	75,000 lb	75,000 lb	75,000 lb	69,000 lb
Earth/Mars spacecraft	50,600	28,850	21,200	36,150
Mars entry capsule	22,300	26,750	7,100	7,100
Mars landed weight	8,920	8,920	3,550	3,550
Mars/Earth spacecraft	580	580	630	660
Earth reentry capsule	50	50	55	55
<u>Key Features</u>				
	Least complicated mission	Direct entry reduces initial S/C weight, but increases G & C requirements	Rendezvous before return reduces initial S/C weight, but increases G & C requirements	Rendezvous before & Venus swingby during return reduces initial S/C weight & stay time in exchange for most stringent G & C

Note: All Earth launches in September 1975. Weights in Earth lb.

assumptions which were made in order to determine these total weights require further verification and are specifically noted in the report conclusions.

AMSR mission feasibility appears to hinge on the demonstration of either of two new capabilities. These are

- the ability to soft-land a 8-10,000 lb launch vehicle and ancillary equipment on Mars (Mode 1 and 2), or
- the ability to rendezvous and dock two unmanned spacecraft in Mars orbit (Modes 3 and 4).

A number of specific subjects are recommended for continued analysis in order to further determine the value and feasibility of AMSR missions. These subjects include:

- Determination of the scientific objectives applicable to AMSR missions,
- Evaluation of the sample size, and the collection and storage requirements,
- Analysis of Mars landing site availability and fluctuation with launch opportunity and Mars intercept options,
- Investigation of changing weight requirements and new mission modes (e.g., outbound Venus swingbys) with later launch opportunities,
- Analysis of rendezvous and docking schemes and associated systems design requirements,
- Definition of optimum descent profiles for heavy (8-10,000 lb) Mars landers,
- Comparison of assumed structure factors with available propulsion system hardware and designs,

- Analysis of midcourse requirements with different transfer trajectories (including Venus swingby) and Mars intercept options,
- Determination of payload penalties of launch windows and plane change requirements.

The study results support a continued interest in AMSR missions which should be encouraged at least until these recommendations are satisfied.

Report M-14

Digest Report: Missions to the Outer Planets

F. Narin

May 1967

This report is a digest of a series of advanced planning reports and papers prepared by the Astro Sciences Center over the last two years. As such, it is an overview of the challenges and potential rewards of outer planet missions rather than a detailed discussion of specific aspects of these missions.

The primary source was ASC/IITRI Report M-11, "A Survey of Missions to Saturn, Uranus, Neptune, and Pluto." However, in order to include Jupiter, information was also taken from the following sources: ASC/IITRI Report P-10, "Critical Measurements on Early Missions to Jupiter;" ASC/IITRI paper, "Choice of Flight Mode for Outer Planet Missions;" ASC/IITRI paper, "The Requirements of Unmanned Space Missions to Jupiter."

The basic conclusion of these reports and papers is that scientifically interesting missions to the outer planets are possible. Flight times range from 1 to 3 years for Jupiter and Saturn to a minimum of 4 years for Pluto with a hypothetical nuclear electric low-thrust stage. Radical technological departures from the current Mariner and Voyager programs do not

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appear to be required for early missions to the outer planets.

Flyby and orbiter missions both should be performed; however, an extensive program of flyby flights is not recommended, because the data attainable from flyby missions are limited in comparison to those provided by orbiters.

For flyby flights, the preferred flight mode is ballistic to Jupiter, and ballistic gravity assist to the other outer planets. The gravity assist mode can be used only in those years in which the planets are correctly aligned. The next launch opportunities for gravity assisted missions utilizing Jupiter are clustered in the 1976 to 1980 time period, followed by a waiting period of 11 to 45 years.

For orbiter missions, a gravity assist mode should not be used, because the high approach velocity in gravity assisted missions actually reduces the payload in orbit to less than that obtainable from direct ballistic flights. For most loose (highly eccentric) orbiters, the ballistic flight mode is satisfactory. However, many circular near planet orbits are not feasible ballistically even with the Saturn V-Centaur; for these missions a nuclear electric low-thrust stage is very attractive.

Report P-18

"Scientific Objectives of Deep Space Investigations:
The Origin and Evolution of the Solar System"

J. M. Witting

September 1966

NASA STAR No. N67-10880

Understanding the origin and evolution of the solar system is one of the primary goals of the space program and many spacecraft experiments and missions contribute to this goal. However the relationship between the individual experiments proposed and this goal is often tenuous. The purpose of this study has been to isolate spacecraft measurements and other future work which are closely tied to an understanding of the origin and evolution of the solar system.

Three broad areas of study have been pursued:

- (1) Present day observations, theories, and experiments which are thought to be boundary conditions on the origin and evolution of the solar system, i.e., facts which must be explained by any complete theory.
- (2) A broad sampling and critique of the more prominent theories which have been derived to explain the origin and evolution of the solar system.
- (3) Future work and experimentation which is necessary to advance our understanding, either by distinguishing among proposed theories, or by contributing to or further defining existing boundary conditions.

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A discussion of the reliability one can place on each of the suggested boundary conditions is given. Where possible, the boundary conditions have been examined as to whether they should be placed on theories of origin or on theories of evolution of the solar system.

The boundary conditions thought to be most relevant to theories of the origin and evolution of the solar system are:

- (1) The angular momentum per unit mass of the Sun is less than that of the planets by a factor of more than 10,000.
- (2) The Sun's rotation speed is not unusual when compared to other stars of the same spectral class.
- (3) The Sun was probably very large and bright for $\sim 10^6$ years; it was then very active during some or all of the next $\sim 10^7$ years; its surface temperature probably never exceeded $\sim 6000^\circ\text{K}$.
- (4) The inclinations and eccentricities of the planets and asteroids are very low; their orbital radii follow an empirical law (Bode's law) approximately.
- (5) Regular satellites have extremely low inclinations and eccentricities; their orbital radii follow a "Bode's law" less well than do the planets.
- (6) The planets and asteroids rotate with small variations in period, except for Venus, Mercury, and Pluto; they tend to have fairly low obliquity.
- (7) The average spatial distribution of matter in the solar system.
- (8) Based on gross physical properties, planets fall into two classes, Jovian (large, low density, low molecular weight) and terrestrial (small, high density, high molecular weight).

- (9) The uncompressed densities of terrestrial planets decrease (slightly) with increasing solar distance.
- (10) The Earth, and probably other terrestrial planets, have much smaller than cosmic abundance of highly volatile elements, including those of high molecular weight.
- (11) Relative abundances of elements which differ in volatility by orders of magnitudes at elevated temperatures, but not at $\sim 300^\circ\text{K}$, do not depart significantly from cosmic abundance.
- (12) The ratio of deuterium to hydrogen is 1.5×10^{-4} , the ratio of Li^6 to Li^7 is .080; the ratio of B^{10} to B^{11} is .232.
- (13) Isotopes of xenon and silver which are β -decay products of radioactive nuclides are overabundant in meteorites.

A large number of theories have been proposed to explain the origin and evolution of the solar system, based on some of the boundary conditions. Almost all theories fall into three classes:

- (1) "Catastrophic" theories postulate a Sun-star encounter,
- (2) "Evolutionary" theories form the entire solar system out of a single contracting cloud of interstellar material, and
- (3) "Mixed" theories postulate a Sun-interstellar cloud encounter.

Many more theories have been proposed than are considered here. Catastrophic theories were once popular. However,

they fail to account for certain very important boundary conditions and are not treated in detail.

Evolutionary theories are confronted with a serious problem in accounting for the angular momentum distribution in the solar system. New fluid dynamical and hydromagnetic principles can make such theories at least plausible. A number of such evolutionary theories have been summarized. The "mixed" theory of Schmidt and his collaborators has also been considered.

The theories tend to diverge at a number of points, some of which are quite fundamental:

- (1) Did the entire solar system originate from a single cloud, or did a pre-existing Sun capture part of an interstellar cloud which ultimately formed planets?
- (2) If the single cloud theory is correct, how did the Sun lose or fail to acquire considerable angular momentum?
- (3) Did planets grow from planetesimals or shrink from protoplanets?

Strengths and weaknesses of each theory considered are pointed out, and a comparison between results of each theory and the boundary conditions set forth earlier has been used to determine those spacecraft measurements and other work which are most closely related to solar system origin and evolution.

Future work having the highest importance is:

- (1) Measurements of interstellar composition, including isotopic ratios, on a mission to solar system escape. This would provide a significant new boundary condition on theories of solar system origin by obtaining a "cosmic abundance" more realistic than presently available, and may modify existing boundary conditions.
- (2) Measurements of the isotopic ratio(s) $\text{Li}^6:\text{Li}^7$, $\text{B}^{10}:\text{B}^{11}$ and/or $\text{C}^{13}:\text{C}^{12}$ on a Jovian planet or a comet. The results would contribute to settling the problem of planetary formation from proto-planets vs. planetesimals.

Other knowledge of clear importance to understanding the origin and evolution of the solar system is:

- (3) He:H ratio on the Jovian planets, especially Jupiter.
- (4) The evolution of stars in their pre-main-sequence phase.
- (5) Xenon (and silver, if possible) isotopic ratios on planets, satellites, asteroids, comets.
- (6) The density of Mercury.
- (7) The magnetic field properties of the planets.
- (8) The heat flux from lunar and planetary interiors.
- (9) The equation of state of iron-nickel, silicates, hydrogen under high pressure.
- (10) Could the planets have been highly inclined or eccentric after their formation?
- (11) The spatial density of, and conditions inside, interstellar clouds.
- (12) The frequency of planetary systems.

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- (13) Interstellar density, temperature, magnetic field.
- (14) Cloud contraction theory.
- (15) The conditions, if any, under which planetesimals can accrete to form planets.
- (16) The exospheric temperatures of each planet.
- (17) In the exosphere, the molecular velocity distribution at high energies.

Report No. P-19

"Scientific Objectives of Deep Space Investigations:
Jupiter as an Object of Biological Interest"

Astro Sciences Center

May 1967

The exobiologists' expectations for finding extraterrestrial life in the solar system traditionally have been focused on the inner planets, with particular attention directed at Mars. Formerly, it was generally believed that the distant outer planets, such as Jupiter, would be too cold, and that their atmospheres might be composed of substances that were inimical to the survival of life, as it is known on the Earth.

This report indicates that the former pessimism regarding the possible existence of life on Jupiter may no longer be justified. Although information about the Jovian atmosphere is at present limited, conditions may prevail on the planet which are compatible with the existence of a primitive biological environment. This assumption is supported by some evidence, as well as recent theories.

The report discusses the Jovian environment; some of the biological systems that conceivably could evolve under such conditions; a brief discussion of current ideas about the origin of terrestrial life; an assessment of the importance of Jupiter

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from a biological point of view; and, the effect of this information on the planning of conventional observations and spacecraft missions to the planets for purposes of scientific exploration.

As ideas about the origin of life on the Earth have become more sophisticated and supported by experimental investigations, it has become reasonably apparent that the conditions which existed on the Earth at the time that terrestrial biogenesis occurred were not unlike those that are assumed to characterize the lower strata of Jupiter's atmosphere. Also, an increasing amount of knowledge obtained about the Jovian environment during recent years suggests the possibility that the planet's atmosphere is highly reducing and that relatively temperate regions containing liquid water as clouds, or even seas, may occur at levels below those which are visible by direct observation. The increased temperatures in the lower strata may be produced in part by the "greenhouse" effect of solar heat trapped in the planet's atmosphere.

Jupiter's atmosphere appears to have the same relative composition as that suggested by the solar abundance of the elements. The Jovian atmosphere is known to contain methane, ammonia, and hydrogen, while the presence of helium is inferred by indirect analysis. The presence of free oxygen and nitrogen

is not expected to be found, however, since in a reducing hydrogen-rich atmosphere, these gases would have combined with hydrogen to form water and ammonia, respectively. Oxygen-containing compounds such as carbon dioxide and carbon monoxide, would similarly be reduced to water and methane, with the water frozen out at the temperatures of the upper atmosphere.

In successful laboratory experiments, simulated Jovian-type atmospheres have been subjected to ultraviolet radiation, electric discharges, ionizing radiation, and heat, which resulted in the production of such compounds as adenine and hydrocyanic acid, as well as amino acids and other complex organic substances. Such compounds generally are considered to be necessary precursors to the simple forms of life, since they form the building blocks for the nucleic acids and proteins which are vital elements of living organisms.

In addition to this evidence for the possible existence of biological precursors on Jupiter, it should be noted that certain types of primitive organisms which presently exist on the Earth also could possibly survive in the Jovian environment. These organisms, as for example, anaerobic methane bacteria (which apparently are able to take in hydrogen and release methane), might have evolved on the Earth under conditions such as those which now exist on Jupiter, and managed to survive to

our era in highly specific micro-environments. Also, consideration must be given to the possibility that life forms in the process of development on Jupiter may have evolved in a manner completely different from that of terrestrial life. An example of this would be the use of liquid ammonia instead of water as a biological substrate.

The origin of terrestrial life is thought to have passed through three distinct chemical phases: inorganic to organic to biological. The generation of life on the Earth's surface must have been preceded by a preliminary development of those organic substances of which organisms are constituted. If positive evidence was found on Jupiter, of the synthesis of organic matter in the presence of a primitive reducing atmosphere, it would provide support for present concepts of the evolution of organized matter. Also, negative findings would be meaningful since they would necessitate reorientation of present thinking as well as a re-evaluation of laboratory experiments employing simulated reducing atmospheres.

The scientific exploration of Jupiter should include additional ground-based or near-Earth observations to obtain more information about the presence of organic molecules, water, and temperature regimes at various atmospheric levels. Such data could later be refined by means of spacecraft flyby and

orbiter missions. However, since ~~the~~ most revealing and interesting part of the planet from the biological standpoint is the region below the clouds, atmospheric probes, survivable and non-survivable, may be required to explore that region. Therefore, spacecraft missions which lead to the deployment of such probes should be given the highest priority for the biological exploration of Jupiter.

The report concludes that presently available evidence regarding the Jovian environment, together with current ideas about the mode for the development of life on the Earth, justify plans for a biological exploration of Jupiter.

Report No. P-20

"Suggested Measurement/Instrument Requirements
for Lunar Orbiter Block III"

W. H. Scoggins and D. L. Roberts

May 1967

This report describes typical scientific measurement and instrument requirements for Lunar Orbiter Block III missions. These missions are planned for the period beyond 1972. The purpose of the study has been to organize information on remote sensing instrument requirements (excluding the metric camera), as an input to a subsequent and independent Phase A study. The metric camera has been indicated where required in this study, but the specifications for it have been undertaken by the Langley Research Center.

In conducting this study, it was necessary to take a broad approach and to consider first what measurements, both orbital and surface, were necessary to completely answer the 15 scientific questions about the moon, posed originally by the Space Science Board (SSB 1965). This approach was taken as far as was necessary to permit the determination of which measurements could be best made from a spacecraft in lunar orbit, and those measurements best made on the lunar surface. Only the orbital measurements were then considered for determination of

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the detailed instrument and measurement requirements. Thus, the surface instrument requirements for lunar exploration specifically have been excluded from the study.

For orbital missions, a preliminary assignment of suitable types of instruments was made from a list of remote-sensing instrumentation which had been generated from the literature. The final phase of the study involved the derivation of a set of suggested measurement and instrument specifications for all of the considered instruments. The decision process utilized at each stage of the study has been that of consensus by a group of scientists. Clearly the decisions are open to review and criticism by the scientific community.

A total of 30 scientific questions, derived from the original 15 SSB questions, have been considered in this study. Of these 30 questions, orbital mission measurements can contribute to answering 22. However, only four of the 22 orbital-related questions could be completely answered by data taken from orbital missions. In making measurements from orbit there are six basic types of measurement requirements which are related to the 13 spacecraft instruments suggested for consideration in planning Lunar Orbiter Block III missions. These measurement requirements, instruments, and instrument purposes, are shown in Table S1.

Table S1

MEASUREMENT/INSTRUMENTATION/PURPOSE
RELATIONSHIPS FOR LOB III

Measurement Requirements	LOB III Instruments	Instrument Purpose
Geometric shape	1. Radar altimeter	Spacecraft altitude
Chemical elemental variation	2. X-ray spec.	Elemental composition
	3. Solar X-ray monitor	Solar X-ray monitoring
	4. Vidicon camera	Percentage shadowing (in conjunction with X-ray spectrometer)
(Surface measurements are also necessary.)		
Material distribution*	2,3,4	Same as above
	5. Multispectral imager	Rock unit identification
	6. Vis-UV spectrometer	Rock signatures
	7. IR spectrometer	Rock signatures
(Surface measurements are also necessary.)		
Active volcanism	8. IR radiometer (3-10 μ)	Volcanic temperature detection
	9. IR-Vis-UV gas spectrum analyzer	Volcanic gas analysis
Tectonic processes*	10. IR radiometer (8-28 μ)	Thermal mapping
	(Surface measurements are also necessary.)	
Atmospheric gases	11. Quadrupole mass spectrometer	Gas analysis
	12. Redhead pressure gauge	Atmospheric pressure

*Metric camera (photographic mapping) is necessary.

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Report No. P-21

"Scientific Objectives for Total Planetary Exploration"

Astro Sciences Center

May 1967

This study provides a method of ordering the objectives of total solar system exploration and of indicating the relative importance of the solar system targets in answering the objectives. It is presented as a possible way of arriving at a total exploration priority system.

The overall goals of space exploration as stated by the Space Science Board have been taken as the starting point. Each goal has been successively expanded into subgoals, gross characteristics of subgoals, scientific objectives, and finally measurable quantities. For each scientific objective, and its related measurable quantities, the importance of each solar system target has been indicated using a 4 symbol rating (I,II, III,IV). These assignments are made on the basis of the contribution of the target to the objective and the contribution of the objective to the overall goals of exploration.

It has been demonstrated, by using a logical method in expanding and explaining the goals of exploration, that it is possible to assess the scientific priorities for total solar system exploration. The pilot study reported here has indicated

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these priorities to a first order. Further refinements are obviously needed both in terms of a more rigorous definition of objective-target priorities and in the summations which lead to the overall ranking of targets and exploration objectives.

The results from this study indicate that the scientific exploration of Mars, Venus, and Jupiter are about equally important and that they extend some way ahead of the other targets. In terms of scientific objectives the exobiological ones rank uniformly high. Although these results are subjective it is felt that reiterations and reappraisals of the data will not make a large difference in the highest priority targets or objectives. This would not be expected to be true of lower ranked ones.

Report No. S-4

"Thermophysical Aspects and Feasibility of Jupiter
Atmospheric Entry"

J. E. Gilligan

June 1967

The principal difficulty in successfully penetrating the upper atmospheres of the outer planets arise from the characteristically high entry velocities. At Jupiter, for example, the entry velocity would be in the range 48-60 km/sec. These velocities, which are several times larger than typical Earth entry velocities, imply at least an order of magnitude increase in heat transfer magnitudes over those currently manageable in Earth and inner planet entries. The objectives of this study thus are to determine the thermodynamic feasibility of such entries, and to delineate the major associated technical problem areas. The study concludes that a surviving entry into Jupiter's lower atmosphere can be accomplished, but it also points out that there are many major assumptions inherent in this judgment.

Interest in exploring outer planets stems from several branches of science, notably astronomy, the geosciences, and exobiology. All have questions which cannot be answered without detailed knowledge of what lies below the visible cloud decks.

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Although interest centers on Jupiter, the general questions are: what is the composition and structure of the atmosphere? Is there a classical surface and where? Is the lower atmospheric environment biologically active, pre-biotic or sterile? Also, present views strongly contend that an understanding of Jupiter's massive interior structure holds the key to many fundamental questions about the origin and evolution of the solar system.

Much of the information sought cannot be obtained unambiguously using current techniques. Spectroscopic and occultation measurements from flybys and orbiters, and ground-based observations can yield information which is pertinent mainly to the atmospheres above the clouds. And, unfortunately, those techniques which do involve deep cloud penetration do not give composition data. An atmospheric probe offers the distinct advantage of acquiring composition, structure, and other data which are correlatable both spatially and temporally.

A concept of successful atmospheric penetration has been defined in terms of "survival criteria"; viz, that, at entry into the cloud tops, an entry probe retain at least 10 percent of its initial mass and that its velocity be no more than 1 km/sec. With these criteria and under stated assumptions, it is shown that only grazing entry trajectories are feasible.

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However, because of the conservatism used in the heat absorption estimates, the more objective conclusion is that in the context of the "survival criteria" grazing entries are always superior to angle or direct entries.

The basic feasibility data were obtained in an IBM 7094 Fortran II computer program which calculates instantaneous convection and radiation heat absorption rates at the stagnation point and which integrates these quantities over the entry trajectory. Mass loss estimates were derived from total heat absorption estimates by assuming a constant heat of ablation (2500 cal/grams). A fractional ablated mass loss was then computed by comparing the mass lost by ablation with the original vehicle mass, assuming a constant ballistic coefficient during entry. The fractional mass loss and the "terminal velocity" (velocity at entry into the cloud tops), are the prime elements of the survival criteria.

In performing the work reported here we found theoretical, and especially experimental, data to be inadequate in several major areas. As a result it was necessary not only to be conservative but to be as concerned with consistency as with accuracy in the thermodynamic performance estimates. The major technological problem areas which must be developed in support of detailed outer planet entry studies are:

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- Planetary atmospheric composition and structure, especially helium abundance
- Theoretical and experimental helium and hydrogen radiative data and laboratory helium and hydrogen thermodynamic and transport data
- Comprehensive hypersonic heat transfer prediction schemes (for radiation-dominated flow fields)
- Ablator materials performance.

Some of the more important individual problems include:

Ablation induced changes in the ballistic coefficient

Influence of ablation products on heat transfer

Ablation product reactions with flow stream

Helium-hydrogen reactions

Ablator and ablation product radiative properties

Boundary layer gas injection benefits

Helium convective heating

Definition of free molecule and transition regimes

High 'g' structures and mechanical design

Upstream radiative heating, and

Optimum initial shape.

Many important non-thermodynamic considerations, such as communications, terminal guidance, payload science, etc., are recognized but have not been specifically included in this study.

In the following figure is shown the fractional ablated mass loss, F_m , and the "terminal" velocity, V_t , as a function

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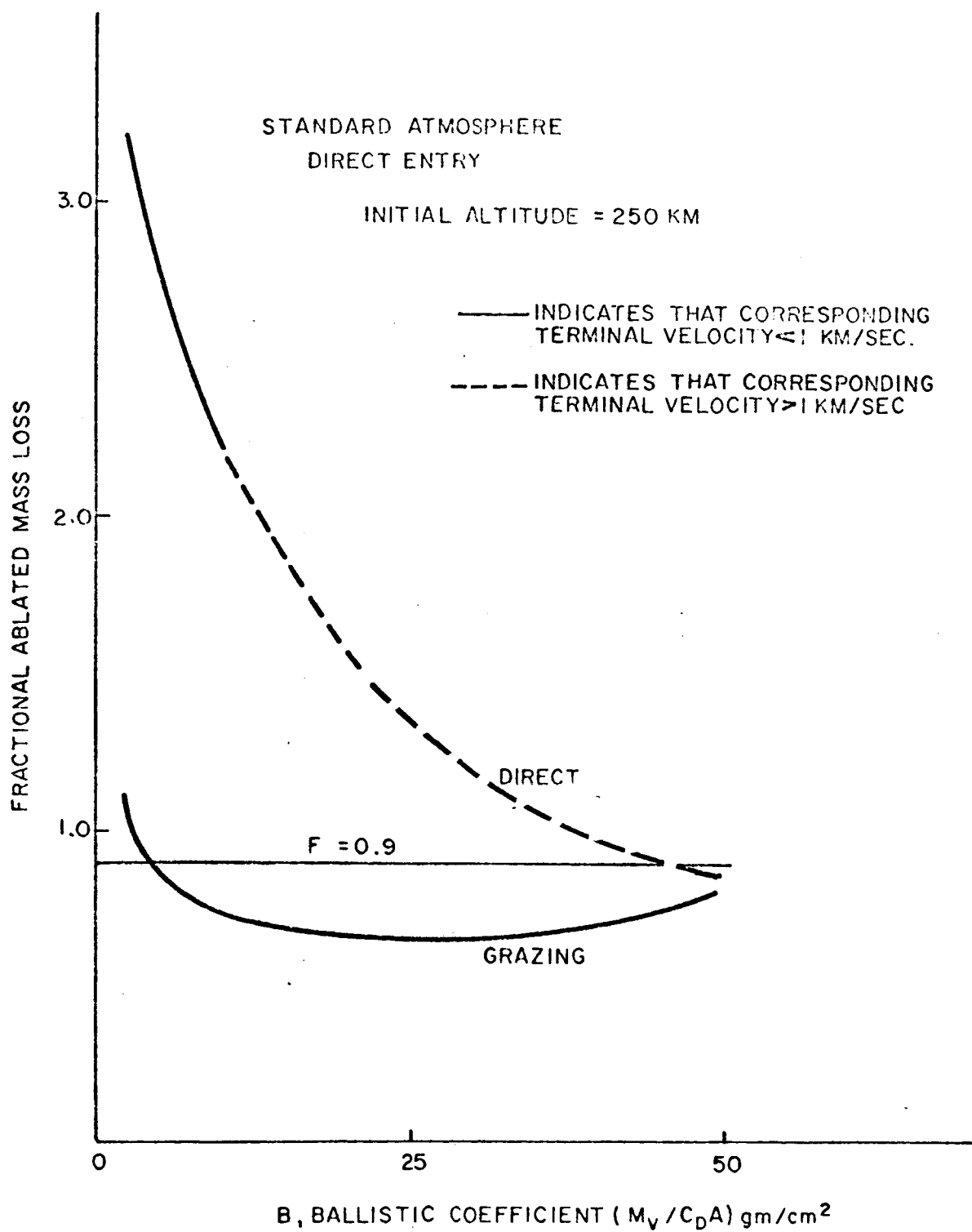


FIGURE S1. SURVIVAL RESULTS - FRACTIONAL MASS LOSS DUE TO ABLATION VS. BALLISTIC FACTOR.

of the ballistic coefficient, B , for Jupiter entry. The values of F_m greater than 1.0 are, of course, unreal. From these data it is evident that direct entries are non-surviving - either because of excessive mass loss at low B values or because of excessive terminal velocities at higher B values. Reflecting the strong influence of the high rotational speed of the planet, the grazing entries survive over a rather wide range of ballistic factors. Notably, the grazing entry results do not depend strongly on atmospheric parameters, nor on the vacuum miss distance, h_p . Also of interest is the fact that although a decrement of 6 km/sec (by rocket braking) has a noticeable effect on survivability, the mass penalty incurred in the rocket case is substantially greater than the ablated mass loss for the same decrement.

Report No. T-18

"The Accessible Regions Presentation of Gravity-Assisted Trajectories Using Jupiter"

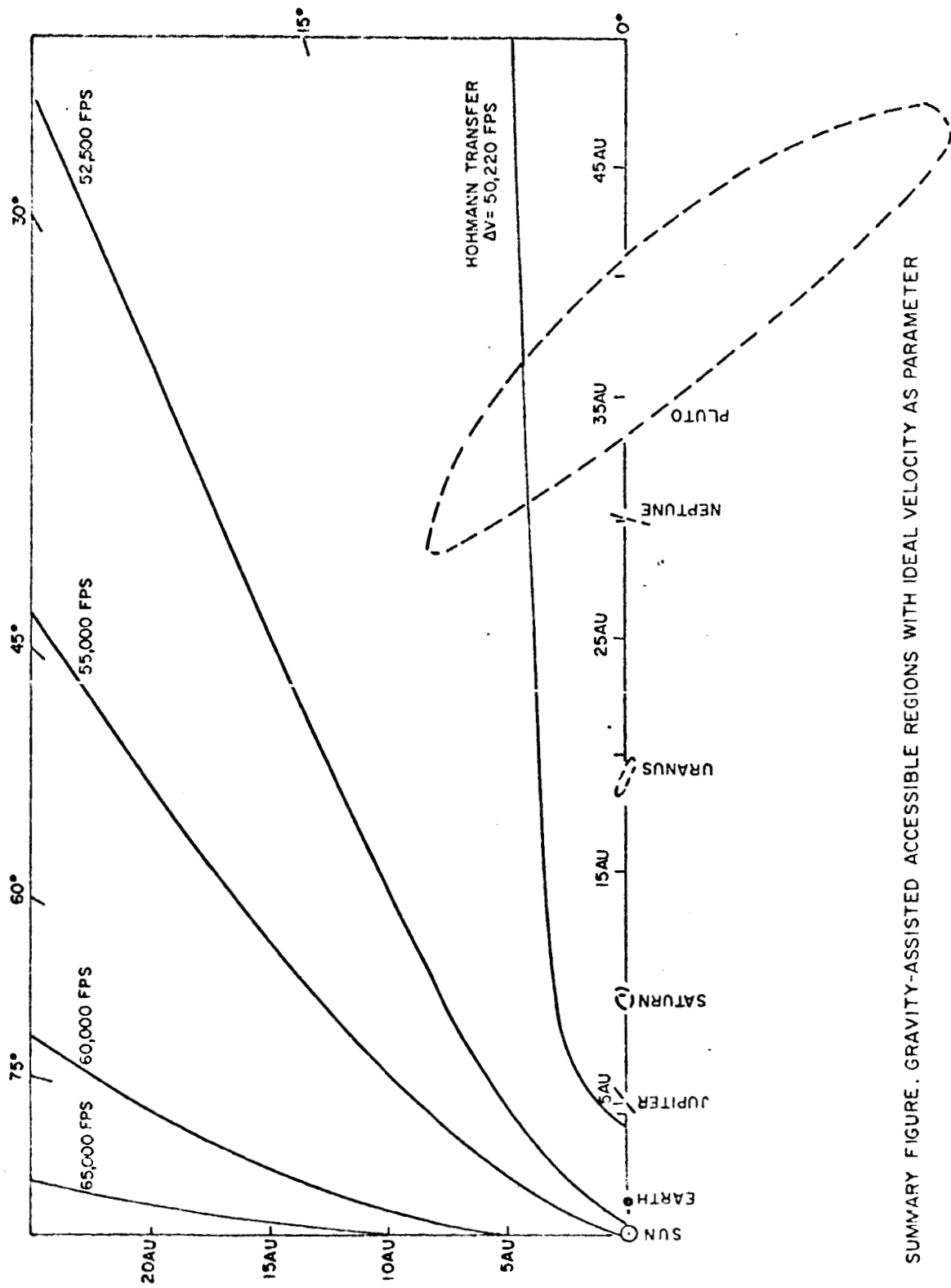
D. A. Klopp and J. Niehoff

June 1967

The exploration capabilities of a given spacecraft-launch vehicle combination are greatly increased by a Jupiter gravity-assist (swingby) maneuver. Many regions of the solar system, which are inaccessible in the direct ballistic flight mode, can be reached by spacecraft using Jupiter gravity-assisted trajectories. For example, this technique permits a spacecraft, launched with an energy just sufficient to reach Jupiter, to explore regions of the solar system far beyond the orbit of Pluto and to climb as high as five astronomical units (AU) out of the ecliptic plane. Greater heights can be attained with only slightly larger launch energies. Solar impact can be achieved far more readily than in the direct ballistic flight mode.

The study results are presented as contours (regions) of accessibility on a latitude-radius (P_N) plane normal to the ecliptic plane for constant ideal velocities (launch energies). Each contour envelops the latitude-radius space traversed by all the constant ideal velocity trajectories passing close to

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SUMMARY FIGURE. GRAVITY-ASSISTED ACCESSIBLE REGIONS WITH IDEAL VELOCITY AS PARAMETER

Jupiter. The ideal velocity is the total velocity increment given to a spacecraft launched from Earth. The summary figure shows contours on the P_N plane for ideal velocities of 50,220, 52,500, 55,000, 60,000, and 65,000 feet per second. These contours are symmetrical about the ecliptic plane and therefore only the upper half of the contour is shown. These contours show, for example, that the entire solar system (except for a small volume more than 10 AU above and below the Sun) can be explored by spacecraft having ideal velocities of 65,000 feet per second.

Gravity-assisted ideal velocity contours, with maximum time of flight as a parameter, are compared with analogous contours based on direct ballistic flight trajectories. An interesting comparison of regions accessible with ballistic, Jupiter gravity-assisted and nuclear electric low thrust flight modes is also given in the text. Additional study of Venus and Mars gravity-assisted trajectories using the accessible regions method of analysis is recommended.

Report No. T-19

"On the Problem of Comet Orbit Determination
for Spacecraft Intercept Missions"

A. L. Friedlander

May 1967

The scientific exploration of comets by means of spacecraft intercept missions presents problems in several important technical areas. One of the key problems in planning such a mission is the magnitude of the uncertainty or error in our present knowledge of the orbital motion of many periodic comets of interest. This uncertainty is a major determinant of how accurately a spacecraft may be guided to intercept a comet. In order to obtain the best viewing conditions of a comet's nucleus, the "miss distance" between the spacecraft and comet should be about 1000 km, and no greater than 10,000 km. This requirement is several orders of magnitude smaller than the errors associated with comet position ephemerides (prediction based on past observations).

This report discusses the factors which contribute to the inaccuracy of comet orbit determination and prediction, presenting illustrative numerical results for the two short period comets, Encke and D'Arrest. The main contributing factors are (1) the restricted arc of the total orbit over which a

comet can be observed from Earth, (2) the relative inaccuracy in measuring right ascension and declination, possibly including large systematic errors, (3) the sensitivity due to planetary perturbations, (4) the possibility of ill-defined non-gravitation forces or secular accelerations acting on the comet, and (5) computational errors of numerical integration. Generally, it is shown that miss distances under 10,000 km cannot be achieved unless the comets are observed during the year in which the spacecraft is launched.

The numerical analysis is facilitated by the COMET ORBIT DETERMINATION PROGRAM which has been developed for use on the IBM 7094 computer. The computer program is designed to integrate the orbit of a comet under the combined gravitational influence of the Sun and planets and other non-gravitational forces, and to process either actual or simulated comet observations in order to determine the most probable estimate of the comet's past or future motion. Also computed is a measure of the orbit determination uncertainty and the resultant miss distance for future missions of interest.

In the case of comets Encke and D'Arrest, the mission examples chosen are in 1974 and 1976, respectively. Past observations of comet Encke are obtained and processed for seven appearances over the period 1931-1961, and for comet D'Arrest,

four appearances over the period 1910-1950. The best results of the data fitting process for each of these comets are obtained for the last several appearances in the above series.

The best estimate of Encke's orbit and its statistical uncertainty obtained for the data fit of the 1947, 1957, and 1961 apparitions is extrapolated to the 1974 apparition and mission of interest. Summary Table I lists the estimated values of miss distance due to the ephemeris error of Encke. With a priori information from the previous apparitions, the miss distance is as large as 70,000 km if no new observations are made in the year of launch. An observation schedule beginning at recovery of the comet and ending one week before launch will reduce the miss to 7,000 km. Further observations beyond the launch data act to reduce the miss, slowly at first, and then rapidly as the observation geometry improves with the decreasing distance between Earth and Encke. To achieve a desirable miss distance of under 1,000 km, the observation schedule must extend to the later portion of the flight - within 20 days of encounter. This implies a late midcourse correction, but only about 4 m/sec.

For comparison purposes, Summary Table I also includes the estimated miss distance when no a priori information is assumed. This would correspond to a worst-case situation

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Summary Table I

ESTIMATED MISS DISTANCE FOR 1974

MISSION TO COMET ENCKE

- Launch Date T_L , 1974 February 7
- Encounter, $T_L + 110^d$
- Recovery, $T_L - 160^d$
- Observations at 8 Day Intervals Beginning at Recovery
- Observation Error, 2 Sec Arc
- A Priori Data, Orbit Determination from Observations in 1947, 1957, 1961 Appearances

<u>Number of Observations</u>	<u>Miss Distance (1σ)</u>	
	<u>A Priori Data</u>	<u>No A Priori</u>
None in Year of Launch	70,000 km	∞
19, Ending $T_L - 8^d$	7,000	17,000
21, Ending $T_L + 8^d$	6,500	14,000
28, Ending $T_L + 64^d$	3,200	10,000
31, Ending $T_L + 90^d$	1,000	4,000
32, Ending $T_L + 98^d$	500	2,000

wherein no confidence is given to a previous orbit determination. Although it is unlikely that a mission would ever be planned under such adverse conditions (recovery of the comet could not be assured), the results are useful in placing an upper bound on the orbit determination problem.

Summary Table II presents similar results for a 1976 mission to comet D'Arrest. The initial miss distance estimate of 108,000 km is based on the observational data fit of the 1943 and 1950 appearances. However, this result may be too optimistic since the 1943-50 orbit could not be accurately linked with the observations taken in earlier appearances. In any event, the analysis shows that observation of D'Arrest taken in the year of launch would be very effective in reducing the miss distance uncertainty. Even in the worst case of no a priori information (assuming that the comet can be recovered), a 1000 km miss distance is still attainable but requires a ΔV correction of about 40 m/sec made 14 days before encounter.

This report recommends that further attention should be given to the orbit determination of each of these comets, especially comet D'Arrest. The present analysis can be updated with later observational data which were not available at the time this analysis was performed. In addition, an effort should be made to improve the ephemerides of other comets which are of

Summary Table II

ESTIMATED MISS DISTANCE FOR 1976

MISSION TO COMET D'ARREST

- Launch Date T_L , 1976 April 21
- Encounter, $T_L + 130^d$
- Recovery, $T_L - 100^d$
- Observations at 8 Day Intervals Beginning at Recovery
- Observation Error, 2 Sec Arc
- A Priori Data, Orbit Determination from Observations in 1943, 1950 Appearances

<u>Number of Observations</u>	<u>Miss Distance (1σ)</u>	
	<u>A Priori Data</u>	<u>No A Priori</u>
None in Year of Launch	108,000 km	∞
11, Ending $T_L - 12^d$	4,500	125,000
14, Ending $T_L + 12^d$	3,300	46,000
18, Ending $T_L + 44^d$	1,900	14,000
22, Ending $T_L + 76^d$	1,000	4,300
27, Ending $T_L + 116^d$	480	1,000

interest for future exploratory space missions. This applies particularly to comets which do not have excellent observational geometries in the year of launch as do comets Encke and D'Arrest. Such an effort will result in the increased probability of recovering the comet during the year of spacecraft launch and tend to reduce the ΔV requirement of late trajectory corrections.

2.2 Technical Memoranda

Technical Memorandum No. P-15

"Analytical Techniques for the Investigation of
Distributional Features of the Asteroids"

J. Ash

January 1967

Examination of the present understanding of asteroidal distributions leads to the conclusion that the motions of the asteroids are not yet very well understood. Statistical analyses based upon the examination of observational data are presently at a rudimentary stage due principally to the limited number of asteroids that are large enough to be observed from the Earth. Mathematical and mechanical analyses have yet to provide definitive solutions which are valid over a long enough time period, and it is possible that certain dynamical problems may never be resolved.

A previous ASC/IITRI report* has reviewed general methods of analysis for the interpretation of asteroid observational data and their significance, and has suggested further observations, from the Earth and from spacecraft, which could support and extend existing theoretical analyses. The purpose of this report is to review in more detail the theoretical

*Analytical Methods and Observational Requirements for Interpretation of Asteroid Distributions, ASC/IITRI Report P-14.

approaches which have been used to determine the distributional features of the asteroids and from which the suggested observations were derived. An attempt is made to discuss critically the most significant analyses of asteroidal distributions. The limitations of the methods are discussed, and a new approach to the problem of distinguishing asteroid families and estimating ages is formulated based upon the techniques of ergodic theory.

Statistical analyses seek collective properties of asteroids by means of empirical and heuristic distribution hypotheses. The recent work of Jaschek and Jaschek and of Anders relies on the extensive survey observations of the relatively large asteroids obtained in 1958 by Kuiper and his co-workers. Estimates of the collision and dispersion half-lives between 5×10^6 and 6×10^9 years have been calculated for families of asteroids.

The analyses based on classical celestial mechanics rely heavily on perturbation theory, which has major limitations. In particular, it is well recognized that even for only three bodies, there is no complete analytic solution which describes the behavior of the motions over sufficiently long periods of time. However, much useful information can be derived from the equations of classical celestial mechanics without actually obtaining complete solutions to the equations. In particular,

the Hirayama families and the Kirkwood gaps have been derived and are at least partially understood. This understanding should be enhanced if computations can be extended to include higher-order terms and if more suitable canonical transformations can be found. Re-examination and extension of the higher-order terms of the disturbance function may permit computations valid sufficiently far back in time to determine collisional origins.

The method suggested in this report for the computation of expected lifetimes of asteroid fragments is based on the use of ergodic theory. The computations remain to be done. If successful, then from a number-frequency plot of the asteroids versus lifetimes, the clustering of asteroids at distinct points will provide a criterion for distinguishing groups with probable common origins. In addition to providing a basis for the formation of dynamically significant groups, this method could yield a direct estimate of the group age.

The overall conclusion concerning this study of asteroidal distributions is that more analysis is required. The most promising sources of gaining deeper understanding are to be found in the application of modern mathematical methods.

Technical Memorandum No. P-17

"A Geological Analysis for Lunar Exploration"

W. Scoggins

August 1966

This report presents a preliminary analysis of the lunar exploration program. The primary purpose of this study was to analyze the various scientific aspects of lunar exploration in an effort to determine a reasonable planning approach for missions to investigate lunar surface features and processes by both geological and geophysical techniques.

The scientific objectives and questions recommended by the Space Science Board (1965)* were taken as a starting point. The major objectives in the exploration of the moon as presented by the Space Science Board are to determine:

1. The structure and processes of the lunar interior,
2. The composition, structure, and processes of the lunar surface, and
3. The history of the moon.

The detailed questions (subdivided and in some cases rephrased) are given in Table S-1.

Lunar characteristics relevant to these scientific questions were considered to determine the extent of

*Space Science Board, Space Research, 1965, Woods Hole, Mass.

Table S-1

SCIENTIFIC QUESTIONS FOR LUNAR EXPLORATION

1. Is the internal structure of the moon radially symmetrical like that of the Earth? If so, is it differentiated? Specifically, does it have a core and does it have a crust?
2. What is the present internal energy pattern of the moon? What is the present heat flow at the lunar surface? What are the sources of this heat?
3. Does the moon have an internally produced magnetic field?
4. What is the geometric shape of the moon? How does the shape depart from fluid equilibrium?
5. What is the average composition of the rocks at the surface of the moon? How does the composition vary from place to place?
6. Are volcanic rocks present on the surface of the moon?
7. What is the range of age of the stratigraphic units on the lunar surface? What is the age of the oldest exposed material? Is a primordial surface exposed?
8. Is there a fundamental difference in morphology and history between the sub-Earth and averted faces of the moon?
9. What is the present tectonic pattern on the moon? What is the distribution of tectonic activity?

Table S-1 (Cont'd)

10. Is the moon seismically active? Is there active volcanism?
11. What are the dominant processes of erosion, transport, and deposition of material on the lunar surface?
12. What volatile substances are present on or near the surface of the moon or in a transitory lunar atmosphere?
13. What are the principal processes responsible for the present relief on the lunar surface?
14. What has been the distribution of tectonic and possible volcanic activity in time.
15. What has been the flux of solid objects striking the lunar surface in the past? How has it varied with time?
16. What has been the flux of cosmic radiation and high-energy solar radiation over the history of the moon?
17. What is the age of the moon?
18. What is the history of dynamical interaction between the Earth and the moon?
19. What is the thermal history of the moon?
20. What past magnetic fields can be recorded in the rocks at the moon's surface?

Table S-1 (Cont'd)

21. Is there evidence for organic or proto-organic materials on or near the lunar surface? Are living organisms present beneath the surface?

exploration. Each type of characteristic is discussed in terms of current lunar theories and of its significance in lunar exploration. The parameters to be measured and the appropriate experimental techniques to answer or partially answer one or more of the questions have been identified for each characteristic considered. Table S-2 summarizes the characteristics, parameters, techniques, and questions answered.

An analysis of the suggested techniques with respect to the number of scientific questions answered by each can be interpreted as relative importance or priority. Sample return provides information for eleven questions and is ranked first. Medium and high resolution in a combined measurement yield data for eight questions as does geological mapping. The techniques ranked in order of priority are given in Table S-3.

This priority list together with information on the weight, power, volume, etc. of the experiments has been used to evolve a hypothetical mission plan for lunar exploration. The plan, which is not treated in this report, was submitted to NASA as a memorandum and indicates the utility of this approach. An extension of the method to include rank ordering of the scientific questions, the effect of complementary experiments and other factors could provide a sound basis for planning lunar exploration.

Table S-2

LUNAR CHARACTERISTICS AND MEASUREMENTS
RELATED TO SCIENTIFIC QUESTIONS

Characteristics or Features	Parameters	Techniques	Questions
<u>Major Features</u>			
Structure	Internal structure	Seismic (passive & active)	
Interior	Lunar tides	Tidal gravimeter	1, 3, 9*, 10*
Crust	Density distribution	Gravity gradiometer & surface gravity	17*, 18*
	Magnetic field	Magnetic measurements	
Figure	Shape	Altimeter, satellite-tracking	4, 8, 18*
	Density distribution	Gravity gradiometer, satellite-tracking	
<u>Denudation and Deposition Processes</u>			
Erosion	Thermal fluctuation	Thermal measurements	11, 13*, 15*
	Meteorite bombardment	Meteorite measurements and sample analysis	16*
	Solar wind	Radiation measurements and sample analysis	
	Ejecta		
Sedimentation	Meteoritic influx	Meteorite measurements and sample analysis	11, 13*, 15*
	Volcanic lava	Sample analysis	16*
	Ejecta (impact & volcanic)		
<u>Large Scale Lunar Features</u>			
María	Deep subsurface structure	Seismic (active, passive)	2, 5, 6, 7*, 11*
	Density variations	Gravity	13*, 15*, 19*
	Near surface structure	Seismic	20*, 21*
	Temperature variations	IR, μ w, probes (thermal)	
	Heat flow	Probes	
	Crater density	Photography	
	Material	Sampling (petrology & mineralogy)	
Uplands	Subsurface structure	Seismic (active, passive)	2, 5, 6, 7*
Highlands	Depth of unconsolidated material	Seismic, gravity, drill	11*, 13*, 14*
Highland basins	Material (petrology & mineralogy)	Sampling	15*, 17*
	Density variations	Gravity	
Highland mountain chains	Temperature variations	IR, μ w, probes (thermal)	19*, 20*, 21*
	Topography	Photography	
		Geo. mapping	
Tectonic patterns	Seismicity	Passive seismic	2*, 9, 10*
	Volcanic activity	Passive seismic, IR, μ w	13*, 14*, 18*
	Temperature variations	IR, μ w, probes (thermal)	
	Density variations	Gravity gradiometer	

Table S-2 (Cont'd)

Characteristics or Features	Parameters	Small Scale Lunar Features		Questions
		Techniques	Questions	
Primary craters	Subsurface structure	Seismic, gravity	10*, 13*, 14*	
	Crater material	Sampling	15*, 17*, 9*	
Secondary craters	Density variation	Gravity		
	Magnetic variations	Magnetic		
Chain craters	Crater geometry	Photography		
	Temperature	IR, uv, probes (thermal)		
Central peaks	Geometry (size & shape)	Photography, observation	13*, 15*	
	Crater material	Sampling		
Rays	Density variations	Gravity		
	Material	Sampling		
Rilles	Geometry & relationship	Photography, observation	10*, 13*	
	Subsurface structure	Seismic, gravity		
Wrinkle ridges	Density variation	Gravity		
	Material (petrology, mineralogy)	IR, uv, probes (thermal)		
Faults	Temperature	Seismic, gravity	13*	
	Subsurface structure	Gravity		
Lineaments	Density variations	Sampling		
	Material (petrology, mineralogy)	IR, uv, probes (thermal)		
Highland scarps	Temperature	Seismic, gravity	2, 10*	
	Material	Gravity		
Domes	Subsurface structure	Sampling		
	Material (petrology, mineralogy)	Gravity		
Mare scarps	Density variation	IR, uv, probes (thermal)		
	Temperature variation	Photography		
Central pit	Material	Seismic, gravity	13*	
	Subsurface structure	Sampling		

* Indicates questions only partially answered during the investigation of a particular lunar characteristic of surface features. Question 12 is the only question which is not answered during above measurements. However it would be answered by stay-behind environmental equipment as indicated in Table S-3.

Table S-3

TECHNIQUE PRIORITY BASED ON QUESTIONS

Techniques	Questions Applicable	Comments
1. Sample return		
Petro. analysis	5,6,13,9,21	100 meter drill & surface traverse
Chem. analysis	5+, 16+, 21+	
Radioactive anal.	7+, 15,16,17+, 19,20	
Mag. analysis	20+, 18	
2. Photography		
(med-hi resolution)	6,7,9,10,13+, 14+,15+	Coverage of selected surface sites
(low resolution)	7,8,9,13+,15	Total surface coverage
3. Surf. geo. mapping		
(regional)	5,7,8,13+,17,19	Long traverse required Short traverse required
(local)	6,7,8,13,14+, 15+,19+	
4. IR mapping	2,5,6+,9,10	25% surface coverage
5. Passive seismic	1+,2,9,10+	Long term measurements- stay behind equipment
6. Active seismic	1,13,14	Traverse & shock gen- eration required
7. Mag. measurements	1,3+,13,20	25% surface coverage
8. Radar	8,9,18	25% surface coverage
9. Gravity gradient	1,14,18	25% surface coverage

Table S-3 (Cont'd)

Techniques	Questions Applicable	Comments
10. Microwave mapping	2,4,9	25% surface coverage
11. Solar plasma	3,11,16	Long term measurements- stay behind equipment
12. Altimeter profile	4+, 18+	25% surface coverage
13. Micrometeorite flux	11+,15	Long term measurements- stay behind equipment
14. Satellite tracking	4,18	25% surface coverage
15. Gravity (surface)	1,13	Traverse required
16. Heat flow	2+	Possibly need drill hole
17. Tidal gravity	18	Long term measurements- stay behind equipment
18. Radioactive meas.	2	Short traverse & drill hole required
19. Thermal fluctuation	11	Long term measurements- stay behind equipment
20. Atomic & mol. gas	12	Long term measurements- stay behind equipment

+ These indicate first priority for answering questions

Technical Memorandum No. S-5

"Low-Thrust and Ballistic Payload Comparison
for Jupiter Orbiter Missions"

D. Healy and D. L. Roberts

May 1967

The purpose of this study has been to compare the mission effectiveness of a nuclear electric orbiter at Jupiter with a ballistic Voyager type orbiter. It has been concluded that there does not appear to be a need for a payload greatly in excess of the Voyager type capability for early Jupiter orbiter missions. Furthermore, no general criteria which could be used to compare low thrust and ballistic payloads became apparent. However, these conclusions should be qualified in terms of the study constraints.

The present limited knowledge of Jupiter severely restricts the number of advanced or sophisticated orbital experiments that can be envisioned. Certainly many measurements will be required in the atmosphere and on the Jovian surface, but from orbit the major early requirement is for "wide band" exploratory measurements. It may therefore be that the Jupiter orbiter mission has little growth potential (in the context of thrust missions) beyond a Voyager type mission unless atmospheric probes or landers are included. Only unmanned missions

have been considered in this brief study. The usefulness of nuclear electric low thrust spacecraft for manned missions has not been considered.

Thus from a scientific aspect, it appears that the power and weight requirements of Jupiter orbiter missions do not indicate a need for a nuclear electric low thrust system. A mission that taxes the ballistic capability far more would be more appropriate. A Jupiter lander or even a Jupiter sample return mission are suggested.

3. TECHNICAL NOTES

3.1 Prospectus 67

Considerable assistance has been provided to NASA in the preparation of the OSSA Lunar and Planetary Programs Prospectus for 1967. This year a computer program has been written to ease some of the more tedious operations in manipulating all the data into a total exploration plan.

Contributions were made in the definitions of the scientific objectives, the communications requirements, the payload weight compilations, the generation of mission flight parameters, the calculation of orbital parameters at the target, and the rationale for mission requirements. The nature of the effort required a quick response in the solution of all problems which arose throughout the formulation of the mission plans. A series of mission definitions were compiled and each was supported by a series of mission fact sheets.

3.2 Operational Computer Codes

The following are the main computer codes which have been added to the Astro Sciences Center's program inventory during the last year. Most of these codes are considerably more complex and sophisticated than codes added to the inventory in previous years.

3.2.1 SPARC

The JPL general conic section SPARC has been added to the ASC program library. This code has become a mainstay of our ballistic and ballistic gravity assist trajectory calculations. In particular, it has been used heavily for the grand tour mission study and outer planet opportunity calculations.

3.2.2 Gravity Assist Accessible Regions Code

A code has been written to calculate and automatically plot accessible regions contours for gravity assist missions, and has been used very extensively for the gravity assist accessible regions study with Jupiter.

3.2.3 NBODY(IV)

The Fortran-IV version of the Lewis NBODY code has been acquired and made operational at ASC. It has been extensively revised at ASC so that multibody targeting and guidance analysis can be done for the grand tour mission study. This is a high precision targeting program.

3.2.4 Atmospheric Entry Calculations

The AMSR mission study and the Jupiter atmospheric entry study were conducted by combining a series of subprograms to integrate the atmospheric entry of a spacecraft. These pieces are now being combined into a general atmospheric

entry program which will become a standard ASC computational tool.

3.2.5 Guidance and Orbit Determination

Two major programs have been written in this area for orbit determination and orbit determination accuracy estimates. The orbit determination program uses a Kalman filtering technique to determine the most probable orbit from an overdetermined set of points and has been used extensively on our comet orbit determination study for intercept missions. A complementary code, PARODE, has been used for estimating the accuracy of orbit determination in the grand tour mission study.

4. PAPERS PRESENTED AND PUBLISHED

The following are the technical papers presented and published since July 1966 largely as a result of work performed on Contract No. NASr-65(06).

4.1 "The Requirements of Unmanned Space Missions to Jupiter"

by D. L. Roberts

Presented at the DGRR/WGLR Joint Space Meeting, Bad Godesberg, Germany (October 1966). Also published in "Raumfahrtforschung" January-March 1967.

4.2 "Choice of Flight Mode for Outer Planet Missions"

by F. Narin

Presented at the XVII International Astronautical Federation Congress, Madrid, Spain (October 1966).

4.3 "Mars Surface Simulator: Design Considerations"

by J. T. Dockery

Presented at the XVII International Astronautical Federation Congress, Madrid, Spain (October 1966)

4.4 "Comet Orbit Determination"

by A. L. Friedlander

Presented at NASA Symposium on Trajectory Estimation, Ames Research Center (October 1966).

4.5 "Missions to Mars Spur Survey of Bioclean Rooms"

by J. D. Stockham, D. L. Roberts, and R. Zastera

Heating, Piping and Airconditioning (October 1966).

- 4.6 "An Empirical Method for Estimating Unmanned Spacecraft Program Costs"
by C. A. Stone and W. P. Finnegan
Presented at the American Astronautical Society National Conference on Management of Aerospace Programs (November 1966).
- 4.7 "Mission Requirements for the Unmanned Exploration of the Solar System"
by F. Narin
Published in Post Apollo Space Exploration, Volume 20, Part Two of Advances in the Astronautical Sciences (1966).
- 4.8 "Post Apollo Space Exploration," Volume 20, Advances in the Astronautical Sciences
Edited by F. Narin (1966).
- 4.9 "Results of Bioclean Room Survey"
by J. Stockham, C. Hagen, S. Miller, M. Nelson, and D. L. Roberts
Heating, Piping and Airconditioning (May 1967).

5. BIBLIOGRAPHY OF ASC/IITRI REPORTS, TECHNICAL MEMORANDA,
AND MAJOR COMPUTER CODES

5.1 Reports and Technical Memoranda

The following bibliography of ASC/IITRI reports and technical memoranda includes all those published since the beginning of the contract in 1963.

- TM C-3 An Empirical Approach to Estimating Space Program Costs, by J. Beverly, C. Stone and R. Vickers (copies not available)
- R C-4 Progress on Spacecraft Cost Estimation Studies, by J. Beverly and C. Stone (copies not available)
- TM C-5 An Analysis of the Correlation Between Spacecraft Performance and Cost Complexity Factor, by W. Finnegan (copies not available)
- R C-6 Spacecraft Cost Estimation, by W. Finnegan and C. Stone, NASA STAR No. N66-29740
- R C-7 Spacecraft Program Cost Estimating Manual, by W. Finnegan and C. Stone, NASA STAR No. N66-30762
- R M-1 Survey of a Jovian Mission, by ASC staff, NASA STAR No. N64-20643
- R M-2 Survey of a Jovian Mission (U), Confidential (copies not available)
- R M-3 Survey of Missions to the Asteroids, by A. Friedlander and R. Vickers, NASA STAR No. N64-19566
- R M-4 Summary of Flight Missions to Jupiter, by ASC staff, NASA STAR No. N64-26597
- R M-5 Missions to the Asteroids, by ASC staff (copies not available)

- R M-6 A Study of Interplanetary Space Missions, by D. L. Roberts,
NASA STAR No. N65-25003
- R M-7 A Survey of Comet Missions, by D. L. Roberts, NASA STAR
No. N65-30481
- TM M-8 Cometary Study by Means of Space Missions, by F. Narin,
P. Pierce and D. L. Roberts (copies not available)
- R M-9 Missions to the Comets, by F. Narin, P. Pierce and
D. L. Roberts, NASA STAR No. N66-15978
- TM M-10 The Satellites of Mars, by D. L. Roberts (copies not
available)
- R M-11 A Survey of Missions to Saturn, Uranus, Neptune and
Pluto, by F. Narin et al., NASA STAR No. N67-14253
- R M-12 A Survey of Multiple Missions Using Gravity-Assisted
Trajectories, by J. C. Niehoff, NASA STAR No. N66-32440
- R M-13 Preliminary Payload Analysis of Automated Mars Sample
Return Missions, by J. C. Niehoff
- R M-14 Digest Report: Missions to the Outer Planets, by F. Narin
- R P-1 Scientific Objectives of Deep Space Investigations -
Jupiter, by D. L. Roberts, NASA STAR No. N64-19567
- R P-2 Scientific Objectives of Deep Space Investigations -
The Satellites of Jupiter, by D. L. Roberts, NASA STAR
No. N64-19568
- R P-3 Scientific Objectives of Deep Space Investigations -
Comets, by D. L. Roberts, NASA STAR No. N64-19569
- R P-4 Scientific Objectives of Deep Space Investigations -
Asteroids, by D. L. Roberts, NASA STAR No. N64-19570
- R P-5 Scientific Objectives of Deep Space Investigations -
Interplanetary Space Beyond 1 AU, by D. L. Roberts,
NASA STAR No. N64-19571
- R P-6 Scientific Objectives for Mercury Missions, by T. Owen,
NASA STAR No. N64-26599

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- R P-7 Scientific Objectives of Deep Space Investigations -
Venus, by P. J. Dickerman, NASA STAR No. N66-32439
- R P-8 Scientific Objectives of Deep Space Investigations -
Non-Ecliptic Regions, by D. L. Roberts (copies not
available)
- R P-9 Compendium of Data on Some Periodic Comets, by
D. L. Roberts, NASA STAR No. N64-28524
- R P-10 Critical Measurements on Early Missions to Jupiter,
by J. Witting, M. W. P. Cann, and T. Owen,
NASA STAR No. N66-15807
- R P-11 Scientific Objectives of Deep Space Investigations -
Saturn, Uranus, Neptune and Pluto, by P. J. Dickerman,
NASA STAR No. N66-17090
- TM P-12 Regularities in the Solar System Pertaining to its
Origin and Evolution, by J. Witting (copies not
available)
- TM P-13 Comparison Criteria for a Total Lunar Scientific
Exploration Program Study, by C. A. Stone (copies not
available)
- R P-14 Analytical Methods and Observational Requirements for
Interpretations of Asteroid Distributions, by J. Ash,
NASA STAR No. N67-17961
- TM P-15 Analytical Techniques for the Investigation of Distri-
butional Features of the Asteroids, by J. Ash (copies
not available)
- R P-16 Mission Requirements for Exobiological Measurements on
Venus, by W. Riesen and D. L. Roberts, NASA STAR No.
N67-12073
- TM P-17 A Geological Analysis for Lunar Exploration, by
W. Scoggins
- R P-18 Scientific Objectives of Deep Space Investigations:
The Origin and Evolution of the Solar System, by
J. Witting, NASA STAR No. N67-10880

- R P-19 Scientific Objectives of Deep Space Investigations:
Jupiter as an Object of Biological Interest, by ASC
staff
- R P-20 Suggested Measurement/Instrument Requirements for
Lunar Orbiter Block III, by W. Scoggins and D. L. Roberts
- R P-21 Scientific Objectives for Total Planetary Exploration,
by ASC staff
- TM R-1 Comparative Reliability Estimation Method for Mission
Programming, by H. Lauffenburger (copies not available)
- R R-2 Probability of Biological Contamination of Mars, by
A. Ungar, R. Wheeler and D. L. Roberts (copies not
available)
- TM S-1 Study of Photographic and Spectrometric Subsystems for
Voyager, by P. N. Slater and C. Johnson (copies not
available)
- R S-2 Scientific Questions Requiring Advanced Technology:
Asteroid Fly-Through Mission, by J. A. Greenspan,
NASA STAR No. N66-23631
- R S-3 Telemetry Communications Guideline, by M. Stein
(copies not available)
- R S-4 Thermophysical Effects and Feasibility of Jupiter Atmos-
pheric Entry, by J. E. Gilligan
- TM S-5 Low-Thrust and Ballistic Payload Comparison for Jupiter
Orbiter Missions, by D. Healy and D. L. Roberts
(copies not available)
- R T-4R Summary of One Way Ballistic Trajectory Data: Earth to
Solar System Targets, by F. Narin and P. Pierce,
NASA STAR No. N64-19572
- R T-5 Accuracy and Capabilities of ASC/IITRI Conic Section
Trajectory System, by P. Pierce and F. Narin,
NASA STAR No. N64-19603

- R T-6 Accessible Regions Method of Energy and Flight Time Analysis for One-Way Ballistic Interplanetary Missions, by F. Narin, NASA STAR No. N64-28840
- R T-7 Perturbations, Sighting and Trajectory Analysis for Periodic Comets: 1965-1975, by F. Narin and P. Pierce, NASA STAR No. N66-13398
- TM T-8 Comparison of Atlas Centaur and Floxed Atlas Centaur Capabilities in Interplanetary Explorations Using the Accessible Regions Method, by F. Narin (copies not available)
- R T-9 Spatial Distribution of the Known Asteroids, by F. Narin, NASA STAR No. N65-30471
- TM T-10 Collected Launch Vehicle Curves, by F. Narin (copies not available)
- R T-11 Sighting and Trajectory Analysis for Periodic Comets: 1975-1986, by F. Narin and B. Rejzer, NASA STAR No. N65-28347
- R T-12 Analysis of Gravity Assisted Trajectories in the Ecliptic Plane, by J. Niehoff, NASA STAR No. N65-34460
- R T-13 Trajectory and Sighting Analysis for First Apparition Comets, by P. Pierce, NASA STAR No. N65-35845
- R T-14 Low-Thrust Trajectory and Payload Analysis for Solar System Exploration Utilizing the Accessible Regions Method, by A. Friedlander, NASA STAR No. N66-13992
- TM T-15 Mission Requirements for Unmanned Exploration of the Solar System, by F. Narin (copies not available)
- TM T-16 Selection of Comet Missions: 1965-1986, by F. Narin, P. Pierce and D. L. Roberts (copies not available)
- R T-17 Low-Thrust Trajectory Capabilities for Exploration of the Solar System, by A. Friedlander, NASA STAR No. N67-12224
- R T-18 The Accessible Regions Presentation of Gravity-Assisted Trajectories Using Jupiter, by D. A. Klopp and J. C. Niehoff

R T-19 On the Problem of Comet Orbit Determination for Space-
craft Intercept Missions, by A. Friedlander

5.2 Major Computational Codes

5.2.1 Interplanetary Transfers

Conic Section Codes

SPARC: The JPL general conic section code for ballistic and ballistic-gravity assist flights.

ASC CONIC: An extensive collection of programs and subprograms for ballistic and gravity assist flights and accessible regions calculations, and for conic guidance analysis.

High Precision Codes

NBODY(II): The Fortran II version of the Lewis Research Center code has been used for comet perturbation analysis, considering the gravitational effects of Sun and planets simultaneously.

NBODY(IV): The Fortran IV version of this is being revised at ASC for multibody, high precision targeting and guidance analysis.

Low Thrust Codes

JPL CODE: The JPL Calculus of Variations Optimized Thrusted Trajectory Code has been used for optimum interplanetary nuclear electric flight with variable thrust, constant thrust, or constant acceleration.

5.2.2 Near Planet Operations

ATMENT: One of a series of codes for integrating the atmospheric entry for a spacecraft.

ZAYIN: A Fortran II code (from W. P. Overbeck) modified for calculating satellite orbits around the Earth, including oblateness and air drag.

GRNDTRC: Generates lunar ground traces for specified lunar orbits.

TRACE: Generates Earth ground traces for specified Earth orbits.

5.2.3 Guidance and Orbit Determination

ORBDET: Orbit determination for an overdetermined set of points by Kalman filtering.

LTNAV: A low thrust navigation code.

PARODE: An orbit determination accuracy estimating code.

5.2.4 Combinatorial Codes

XPSLCT and COMBSC find various sets of payloads from experiments and instruments, subject to spacecraft constraints.

HFIT: A code for least square fit of a set of points to a hyperbola.

BIMED: A general statistical analysis package from UCLA; used for multiple regression analysis.

IMP3: An integer programming code.

5.2.5 Space Sciences Codes

ASTA: A set of codes for analyzing spatial and velocity distributions of the asteroids.

HAZARD: A code for calculating spacecraft to asteroid and meteor stream distances.

SIGHT: A code for analyzing position of celestial objects.

INTEGRALS: A set of codes for evaluating various special integrals which arise in planetary atmosphere analysis.

5.2.6 Special Features and Systems

GPSS-III: An IBM system for analyses of systems of discrete transactions.

MIMIC: A Fortran IV-like system for simulating, on the 7094, an analog computer and thereby easily doing integrations.

KWIC-II: The IBM key word in context system used to catalog the ASC library of some 8000 documents.

Orbital Elements Tape: An extensive collection of orbital elements for solar system objects, including planets, 1600 numbered asteroids, 2000 unnumbered asteroids and hundreds of comets.

Appendix A

REPORT DESIGNATION AND DISTRIBUTION

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Appendix A

REPORT DESIGNATION AND DISTRIBUTION

Distribution of ASC/IITRI reports is determined on the basis of range of interest or the subject matter. Those felt to be of general interest receive the widest distribution. This category includes some reports as written and digests of the long or technically detailed reports. Reports given wide distribution (see List A) are bound in red for visual identification.

Reports felt to be of more specialized interest including some mission studies and trajectory calculations are given a smaller distribution (see List B). These reports can be identified by the black binder.

Technical memoranda include results of special studies in narrow technical areas, interim reports and other documents involving very limited distribution (see List C). White binders are used to identify technical memoranda.

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